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CDF

Top Quark Mass and Production from CDF

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Top quark mass and production from CDF

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We present the latest results about the top quark obtained by the CDF experiment using a data sample of about 110 pb^{-1} collected at the Fermilab Tevatron collider. We briefly describe the production cross section determination and the top mass measurement. Finally we review the search for the top quark in rare decay channels and the first direct calculation of the CKM matrix element V_{tb} .

1. INTRODUCTION

At the Tevatron energy ($\sqrt{s} = 1.8 \text{ TeV}$) top quarks are produced primarily via the process $p\bar{p} \rightarrow t\bar{t}$. In the Standard Model each top quark decays almost exclusively into a real W and a b quark ($t \rightarrow Wb$). Each W subsequently decays into either a charged lepton and a neutrino or two quarks. The $t\bar{t} \rightarrow W^+bW^-\bar{b}$ events can thus be identified by means of different combinations of energetic leptons and jets. The branching ratio for both W 's from a $t\bar{t}$ pair to decay leptonically is: $2/81$ for $e\mu$, $e\tau$, $\mu\tau$ and $1/81$ for ee , $\mu\mu$, $\tau\tau$ (*dilepton channels*). Decay modes of $t\bar{t}$ pairs in which one W boson decays hadronically and the other leptonically (*single lepton channel*) have a branching ratio of $24/81$. When both W 's decay hadronically (*all hadronic channel*) the branching ratio is $36/81$. CDF searched for the top quark using most of these signatures.

The first evidence for the presence of top events in the data was reported by CDF in 1994 [1][2]. One year later both the CDF and D0 Collaborations announced the observation of the top quark [3][4][5]. After the top discovery the Tevatron experiments have moved to detailed studies of its properties. In this paper we describe some of the most relevant analyses: the measurement of the $t\bar{t}$ production cross section and top mass, the study of its production and decay features such as branching ratios and $t\bar{t}$ invariant mass and the search for evidence of unexpected or rare decay channels signatures.

The following CDF results are based on a data

sample corresponding to about 110 pb^{-1} .

2. PRODUCTION CROSS SECTION

By measuring the $t\bar{t}$ production cross section $\sigma_{t\bar{t}}$ in as many channels as possible, in principle we can test the Standard Model predictions in great detail. The measurement of $\sigma_{t\bar{t}}$ is compared to QCD calculations [6].

In Table 1 we summarize the number of candidate events selected in each channel, the corresponding expected background and the calculated production cross section. The best measurement of the cross section uses $t\bar{t}$ decays into one or two leptons plus multiple jets. Using acceptances calculated for a top mass of $175 \text{ GeV}/c^2$ we find $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6} \text{ pb}$.

In Fig. 1 we show the results of the cross section calculation for each $t\bar{t}$ channel, as well as the combined measurement and the value predicted from theory.

3. MASS MEASUREMENT

The top quark mass is a fundamental parameter of the Standard Model. Precise measurements of the top quark and W boson masses constraint the mass of the Higgs boson.

We obtain the best measurement of the top mass from the single lepton plus jets channel. We start selecting the sample by requiring the presence of at least four jets in each event. Three of them must have an observed transverse energy $E_T > 15 \text{ GeV}$ and pseudorapidity $|\eta| \leq 2$. In

Table 1

Summary of events selected in the various channels, expected background and corresponding production cross section.

Decay Channel	Candidate Events	Expec. Background	Cross Section (pb)
$e\mu, ee, \mu\mu$	9	2.1 ± 0.4	$8.5^{+4.4}_{-3.4}$
$e(\mu) + \text{jets (SVX)}$	34	8.0 ± 1.4	$6.8^{+2.3}_{-1.8}$
$e(\mu) + \text{jets (SLT)}$	40	24.3 ± 3.5	$8.0^{+4.4}_{-3.6}$
All Hadronic	187	142 ± 12	$9.6^{+4.4}_{-3.6}$
$e(\mu) + \tau$	4	2.0 ± 0.4	$15.6^{+18.6}_{-13.2}$
Combined Lepton + jets (SVX and SLT) and Dilepton			$7.5^{+1.9}_{-1.6}$

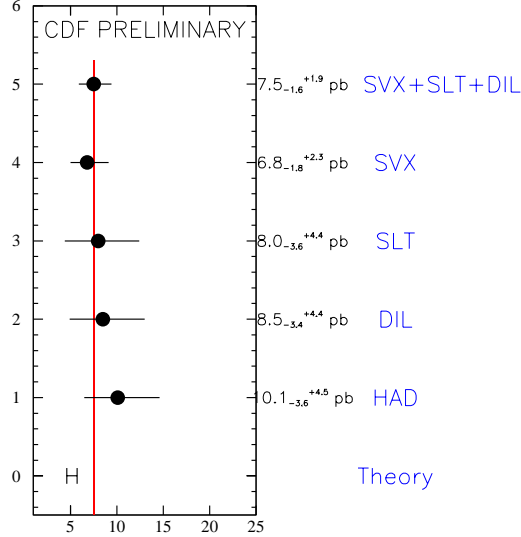


Figure 1. Individual cross section evaluated assuming $M_{top} = 175 \text{ GeV}/c^2$ and combined result. The theory point shows the uncertainty due to the spread of the 3 most recent predictions.

order to increase the acceptance, we require the fourth jet to have $E_T > 8 \text{ GeV}$ and $|\eta| \leq 2.4$, if one of the four leading jets is identified as a b jet (secondary vertex (SVX) or semileptonic (SLT) tag). In case no such tag is present, the fourth jet must pass the same E_T and η cuts as the first three. Each event in the sample is fitted to the hypothesis of $t\bar{t}$ production followed by decay in the lepton plus jets channel. If one or two of the four leading jets are b tagged, they are assigned to b partons. Out of all the possible jets

assignment we keep the solution which has the lowest fit χ^2 . Events for which this lowest χ^2 is too large are rejected. In the top mass sample 82 events survive this requirement. The precision of the top quark mass measurement is expected to increase with the number of observed events, the signal over background ratio and the narrowness of the reconstructed mass distribution. These characteristics vary significantly between samples with different b tagging requirements. Therefore, to make optimal use of all the available information, we divide the top mass sample into four non-overlapping subsamples, based on the tag status: events with a single SVX tag, with two SVX tags, with an SLT tag but no SVX tag and finally events with no b tag. We treat these subsamples separately calculating individual likelihoods. The product of these likelihoods is maximized to determine the top mass and its uncertainty. The reconstructed mass distribution of the sum of the four subsamples is shown in Fig. 2. The data (solid histogram) are compared to a combination of top and background (dashed histogram) and to the background component (shaded histogram). The inset shows the fit likelihood as a function of top mass. The curve has a minimum at $176.8 \text{ GeV}/c^2$. The statistical uncertainty is $4.4 \text{ GeV}/c^2$ and it corresponds to a half-unit change in the negative log-likelihood to respect to its minimum. The main systematic uncertainties come from the jet energy measurement and the presence of gluon jets among the four jets which are used for the top mass reconstruction. The top mass measurement using this

method is:

$$M_{top} = 176.8 \pm 4.4(stat.) \pm 4.8(syst) GeV/c^2.$$

As an internal check, we reconstructed in these events the W which decays hadronically. We used events where both b jets are identified. We found a peak in the dijet invariant mass distribution and measure the W mass to be $78.3 \pm 5.1(stat.) \pm 3.0(syst.) GeV/c^2$. This demonstrates the presence of two W bosons in the single lepton channel $t\bar{t}$ candidate events.

The top mass has been measured also in the dilepton and in the all hadronic channels, with the following results: $M_{top} = 159 \pm 21(stat.) \pm 7(syst.) GeV/c^2$ and $M_{top} = 186 \pm 10(stat.) \pm 12(syst.) GeV/c^2$ [7] respectively. The results, although less precise, are consistent, within their errors, to the value obtained from the lepton plus jets channel.

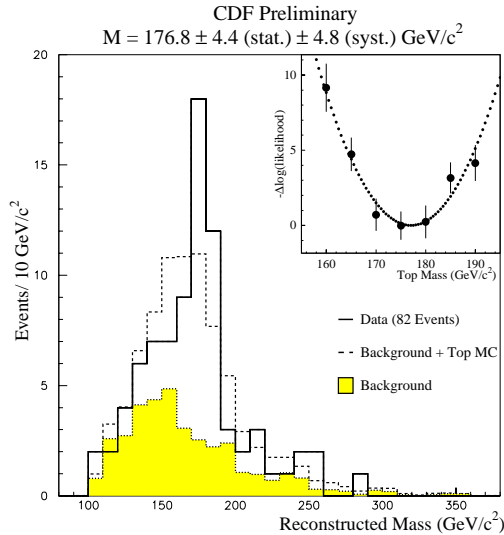


Figure 2. Reconstructed M_{top} of the four combined top mass subsamples. The data (solid histogram) are compared to a combination of top and background and to the background only. The inset shows the negative log-likelihood as a function of top mass.

4. V_{tb} MEASUREMENT

The top quark branching fraction $\mathcal{B} = (t \rightarrow Wb)/(t \rightarrow Wq)$ is predicted to be almost 1 in the Standard Model. Its measurement allows to extract the CKM matrix element $|V_{tb}|$. Assuming CKM unitarity $\mathcal{B} = |V_{tb}|^2$. A large deviation of \mathcal{B} from its Standard Model value would indicate the presence of non-Standard Model effects in the top sector.

In this analysis [8] we use the dilepton sample (9 events) and the lepton plus four jets sample (163 events). Each sample is divided into subsamples according to the presence of identified b tags (0, 1 and 2 tags). We measure \mathcal{B} from the ratios of double b -tagged, single b -tagged and untagged events. Using the efficiency for tagging a b jet and a Monte Carlo model of the b acceptance in top events, \mathcal{B} can be extracted from a likelihood fit. The fit result is $\mathcal{B} = 0.99 \pm 0.29$. In Fig. 2 we show the negative of the likelihood as a function of \mathcal{B} . The confidence level limits are $\mathcal{B} > 0.64$ (0.58) at 90 (95) % C.L.. Assuming unitarity, this result can be converted into a lower limit on $|V_{tb}|$. We find $|V_{tb}| = 0.99 \pm 0.15$ and $|V_{tb}| > 0.8$ (0.76) at 90 (95) % C.L.. However, given the present precision, $|V_{tb}|$ is much better determined from unitarity and independent measurements of the other CKM parameters.

5. TOP KINEMATICS

The comparison of top kinematic properties observed in data with expectations from Monte Carlo is an important tool for testing Standard Model predictions and looking for effects due to new physics. In particular, one would expect a structure in the $t\bar{t}$ invariant mass distribution, if $t\bar{t}$ production was due to the decay of a heavy state. In Fig. 4 we show the invariant mass of the $t\bar{t}$ system in tagged single lepton top candidate events, compared to the Standard Model Montecarlo expectations.

We studied many top and $t\bar{t}$ variables and always found good agreement between data and Monte Carlo predictions.

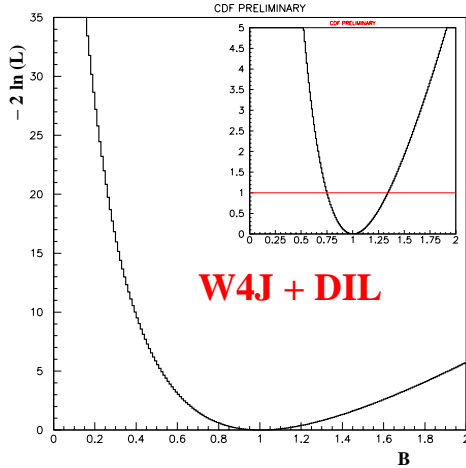


Figure 3. Plot of $-2\ln L$ as a function of B . Inset is a blow-up of the region of the minimum.

6. SEARCH FOR FCNC RARE DECAYS

Within the Standard Model flavor changing neutral current decays of the top quark ($t \rightarrow qZ$ and $t \rightarrow q\gamma$, where q indicates a u or c quark) are suppressed at the level of $10^{-9} \div 10^{-12}$. Physics beyond the Standard Model can alter the expected rates of FCNC interactions.

In this analysis [9] we assume that one top quark in the pair decays via the Standard Model decay $t \rightarrow Wb$ and look for evidence of FCNC decays of the other top.

In the search for $t \rightarrow q\gamma$ we consider two event signatures, depending on whether the W decays hadronically or leptonically. In the first case we require the presence of a photon and four jets. In the second, we require the presence of a photon and an identified W (high energy lepton and missing E_T). In both cases there must be a photon and jet combination with mass between $140 \div 210 \text{ GeV}/c^2$, consistent with the top quark mass. The expected background is mostly due to $W\gamma$ production and is estimated about 0.5 events/channel. One event is observed in the leptonic channel and no events pass the selection in the photon plus multijet channel. In order to set the limit, we assume this event to be signal and we do not subtract the background. The observation

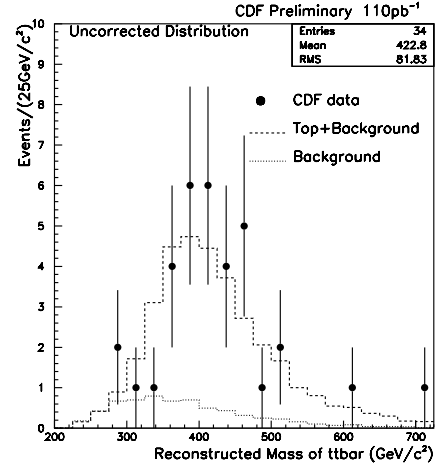


Figure 4. Invariant mass of the $t\bar{t}$ system in single lepton tagged events.

of a single candidate, after taking into account efficiencies, acceptances and related uncertainties, converts in a 95% C.L. limit on the branching fraction: $B(t \rightarrow \gamma u + t \rightarrow \gamma c) < 3.2 \%$.

In the search for $t \rightarrow qZ$ events we use the channel where the Z decays into e^+e^- or $\mu^+\mu^-$ and the other top quark decays into 3 jets. The expected topology therefore is an identified Z plus four jets. Because the Z branching fraction to leptons is small, we expect this analysis to be less sensitive than the $t \rightarrow q\gamma$ search. The main contributions to the background come from Z + jets production and standard top production $t\bar{t} \rightarrow l\nu l\nu b\bar{b}$. A single $Z \rightarrow \mu^+\mu^-$ event survives the selection cuts. As in the previous case no background subtraction is performed. The observation of one event translates to a branching fraction limit: $B(t \rightarrow Zu + t \rightarrow Zc) < 33\%$.

7. CONCLUSIONS

CDF isolated a top signal in the dilepton channels, in the single lepton (e or μ) plus jets channel and in the all hadronic channel and measured the corresponding production cross section.

The best measurement of the top mass comes

from the lepton plus jets channel: $M_{top} = 176.8 \pm 4.4$ (stat.) ± 4.8 (syst.) GeV/c². The measured top pair production cross section is $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb.

Fig. 5 shows the CDF top mass result combined with the W mass measurement. This information, at present statistically too limited, can be used to set some constraints on the mass of the neutral Standard Model Higgs boson.

From the study of many top quark properties, no deviation from the Standard Model expectation has been observed. The data are giving a consistent picture of the top quark as a Standard Model object, even if with the present statistical precision exotic production mechanism and large non-standard branching ratios cannot be ruled out.

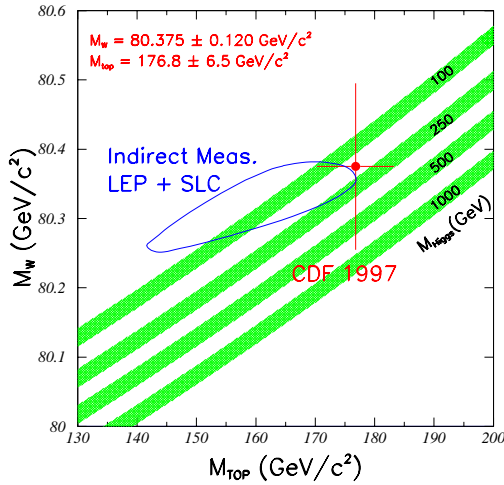


Figure 5. M_W versus M_{top} measured by CDF, compared to Standard Model predictions for various masses of the neutral Higgs boson.

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